Evaluation of Small Mass Spectrometer Systems

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Introduction

Understand Aspects of Designing a
Miniature Mass Spectrometer (MS) System

Systems Evaluated

Linear Quadrupole
Quadrupole Ion Trap
Sector
Quadrupole Array
Time of Flight

Figures of Merit

Accuracy
Limits of Detection
Response Time
Volume
Precision
Scan Rate
Recovery Time
Weight

Set Up Scale to Rank Systems

Why Miniaturize?

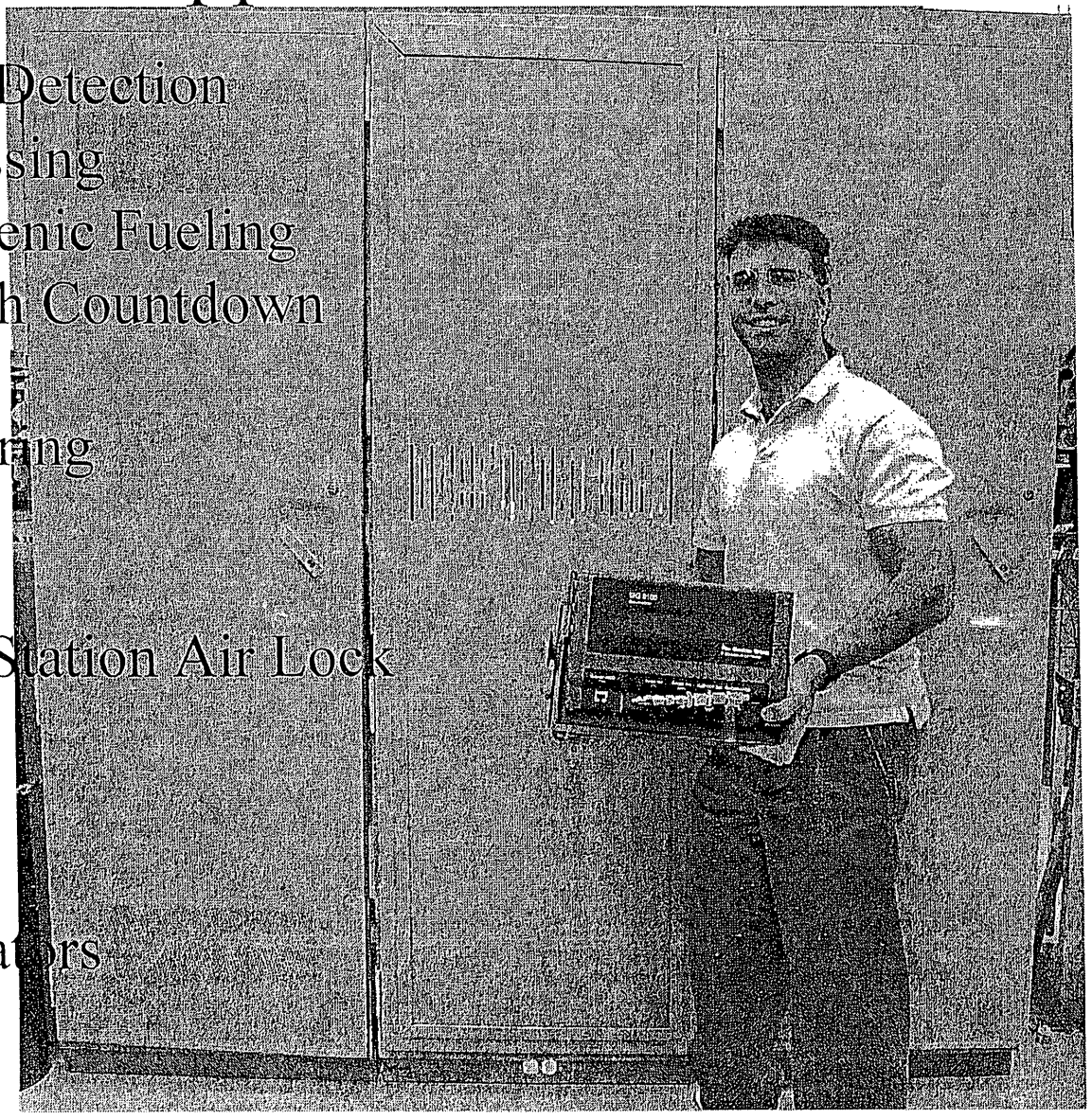
- Improve Portability
  - Field Applications
  - Real-time Analysis
  - Decrease Contamination
- Size Reduction
  - Increase Sensor Density
  - Less Intrusive
- Cost Reduction
  - Less Weight
  - Less Power

Potential Applications

- Leak Detection
  - Hazardous Gases
  - Helium
  - Refrigerants
- Air Analysis
  - Worker Safety
  - Public Safety
  - Chemical Weapons
- Law Enforcement
  - Contraband Detection
- Field Medical Analysis
- Process Control
  - Semi-conductors
  - H_2 Economy

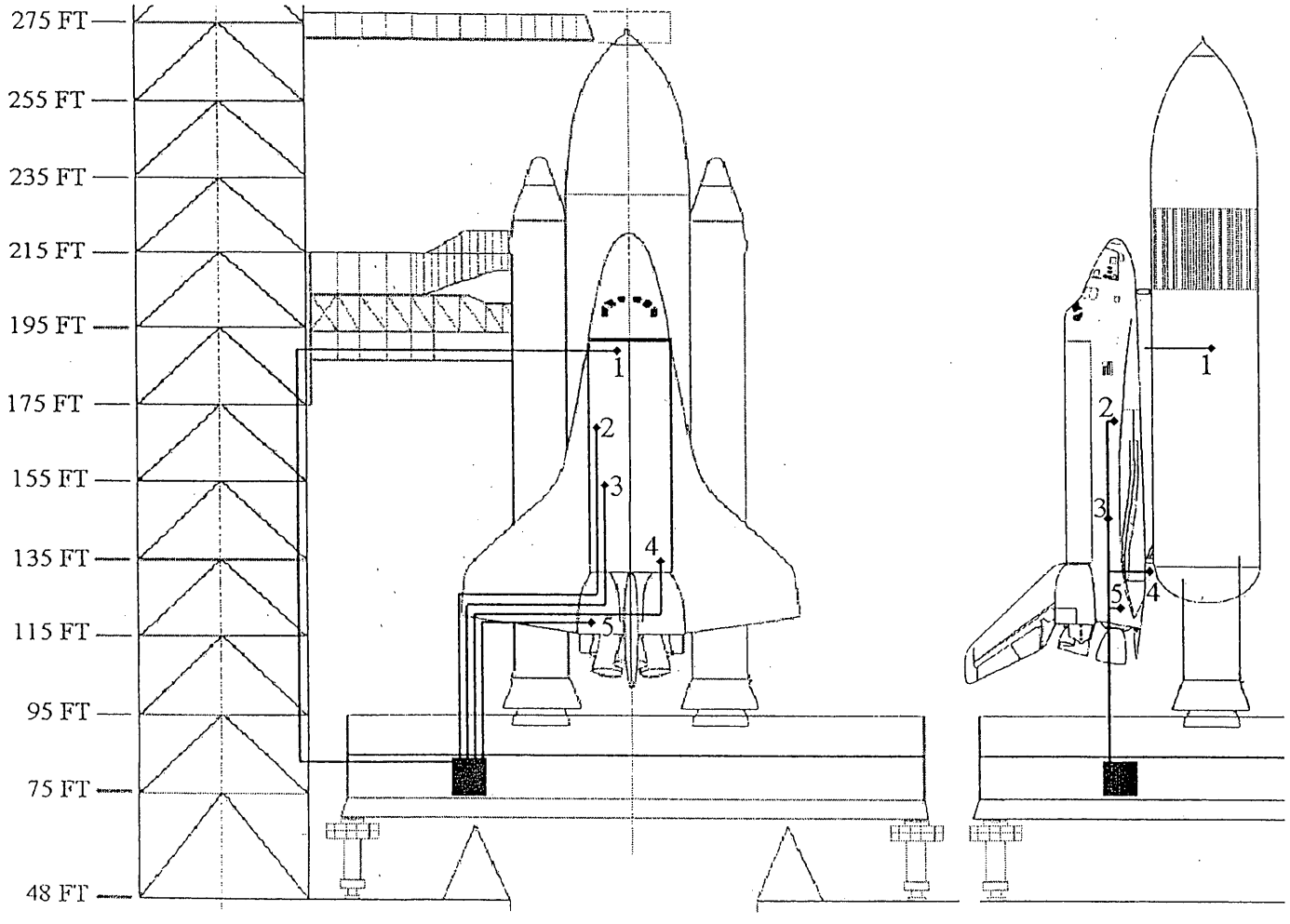
NASA Applications

- Next Generation Leak Detection
  - Leaks During Processing
  - Leaks During Cryogenic Fueling
  - Leaks During Launch Countdown
- Shuttle Engine Monitoring
- Air Analysis
  - International Space Station Air Lock
  - Shuttle Air Lock
- Process Control
  - Martian Fuel Generators



Current Problems

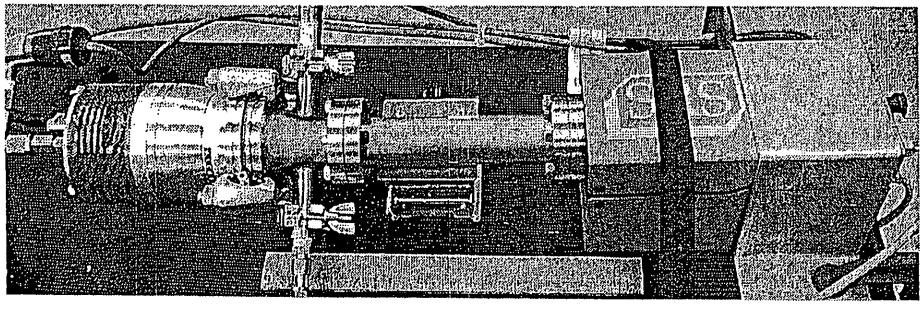
Response Time Scan Rate Sampling Density



SRS & XPR-2

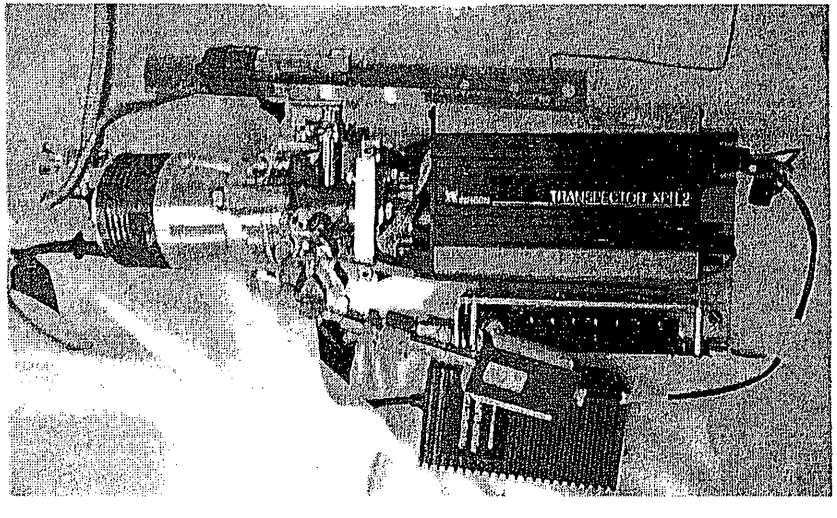
Stanford Research Systems (SRS) RGA-100

- Linear Quadrupole Analyzer
  Cylindrical Rods: 6.35mm OD
  Rod Length:11.4 cm
  Inscribed Radius: xx
  Frequency: 2.76 MHz
- Pressure = 5 x 10^{-5} torr



Inficon XPR-2

- Linear Quadrupole Analyzer
  Hyperbolic Rods
  Rod Length: 12.7 mm
  Inscribed Radius: 0.33 mm
  Frequency: 13 MHz
- Pressure = 1 x 10^{-4} torr



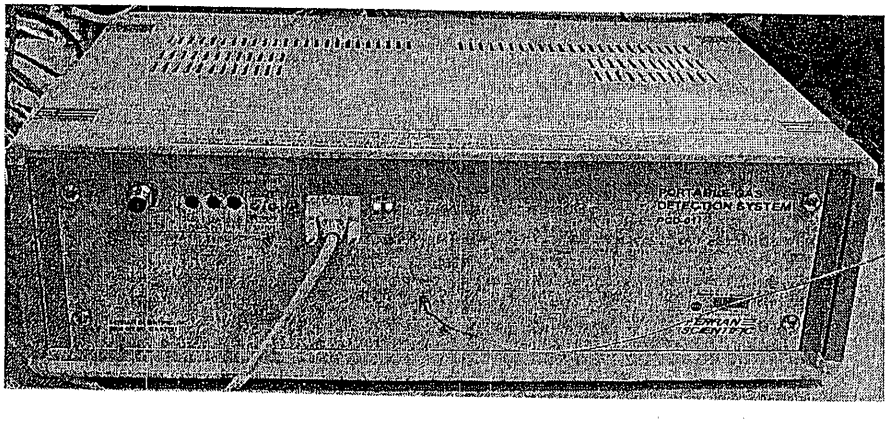
Ferran SRS & XPR

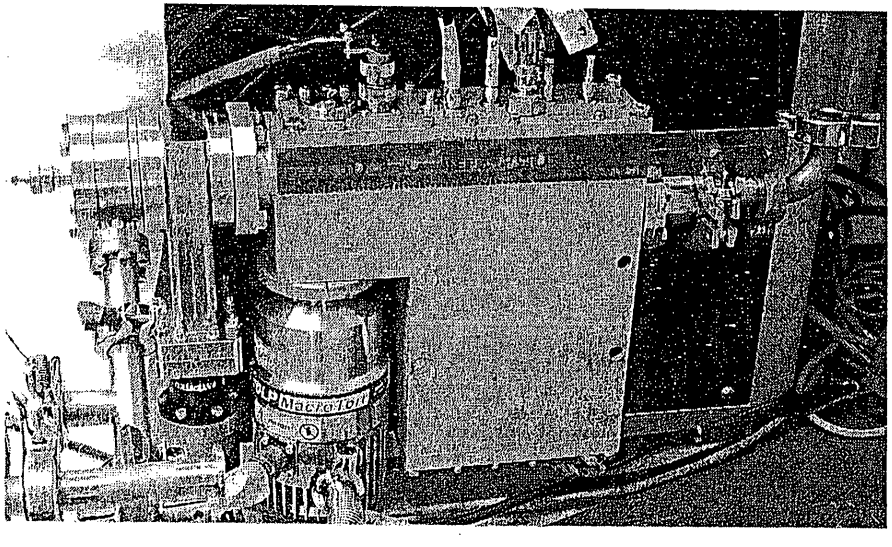
Ferran & TOF

IonWerks Time-of-Flight (TOF)

- Quadrupole Array System
  - 16 Cylindrical Rods: 1 mm OD
  - Rod Length: 10 mm
  - Ω = 16 MHz
- Pressure: ~5 x 10^{-4} torr

- Reflectron TOF System
  - Orthogonal Acceleration
  - Flight Length: m
- Pressure: ~5 x 10^{-6} torr

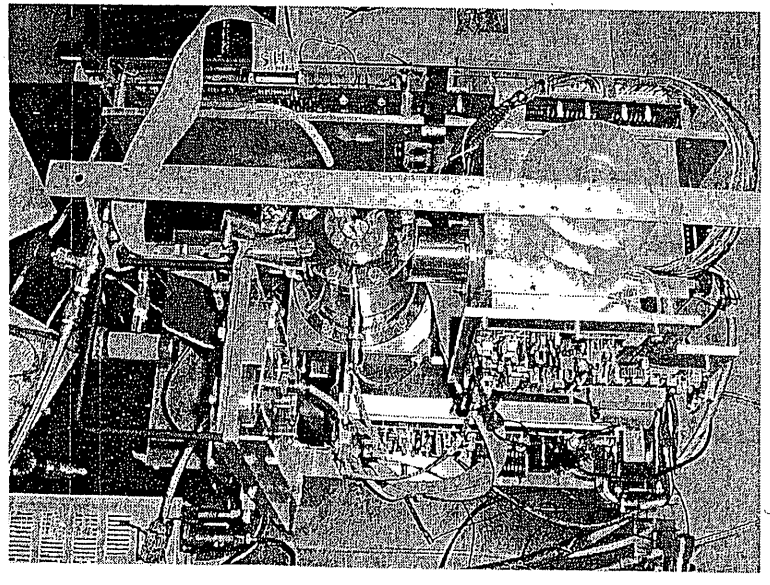




UF-IT & P-Q

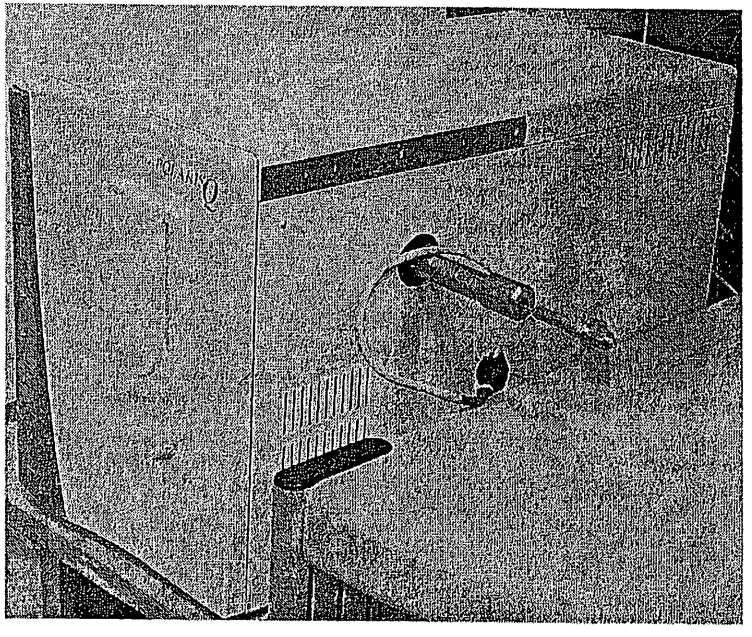
University of Florida Ion Trap (UF-IT)

- Quad. Ion Trap System
  - Ring Radius: 10 mm
  - Stretched Geometry
  - Ω = 2.5 MHz
  - No Buffer Gas
- Pressure: 4 x 10^{-6} torr



Thermo Finnigan Polaris-Q

- Quad. Ion Trap System
  - Ring Radius: 7 mm
  - Stretched Geometry
  - Ω = 1.03 MHz
  - Helium Buffer Gas
- Pressure: 1 x 10^{-3} (4 x 10^{-6}) torr



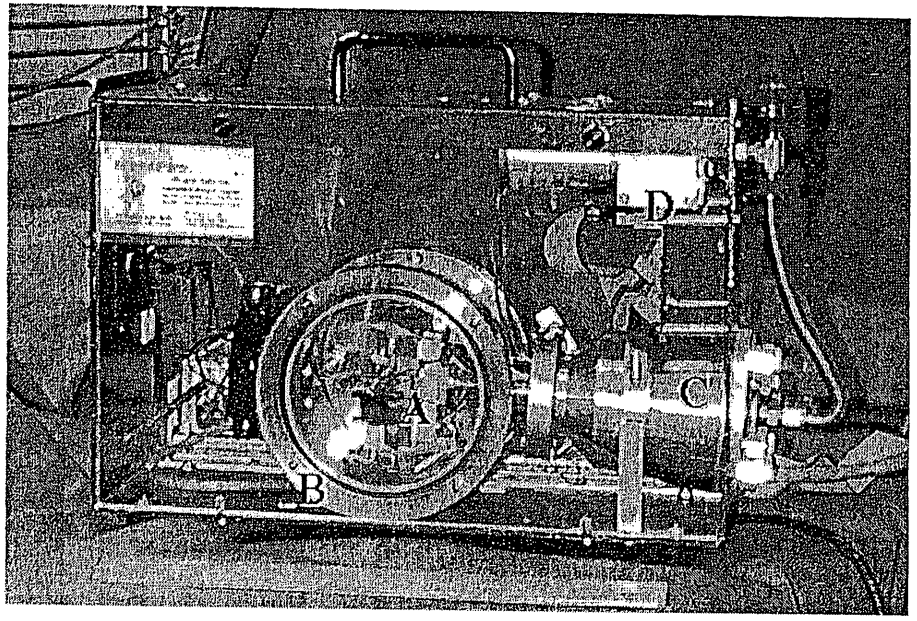
MG & CDFMS

Monitor Group
MG-2100

- Cycloidal Sector System
  B: 0.5 Tesla
  Pitch: 1inch
- Pressure: ~5 x 10^{-6} torr

University of Minnesota
Compact Double Focus MS (CDFMS)

- Double Focus Sector System
  B: 0.75 Tesla
  Sector Radius: 20 mm
- Pressure: 10^{-5} torr

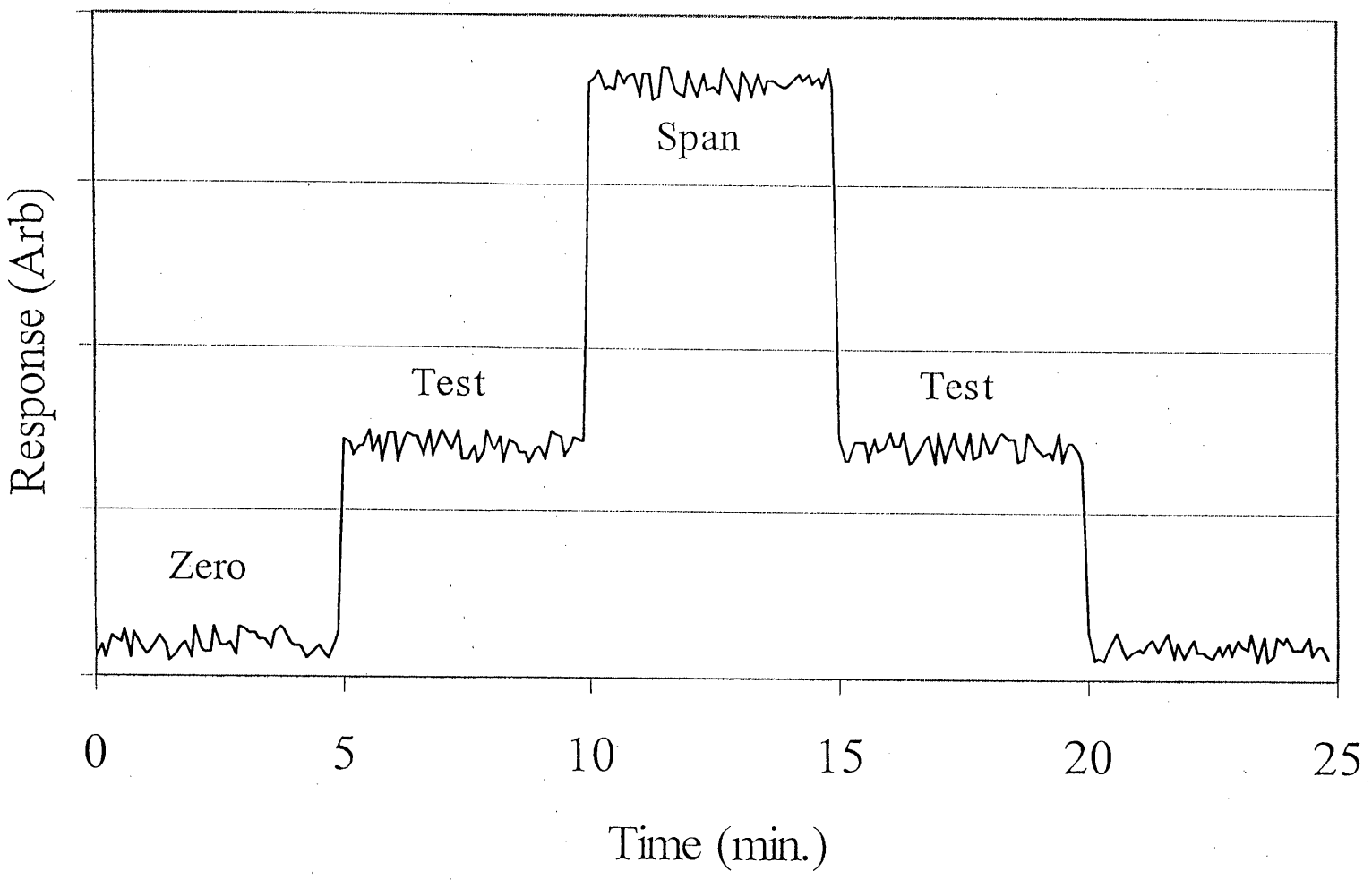


Experimental Parameters

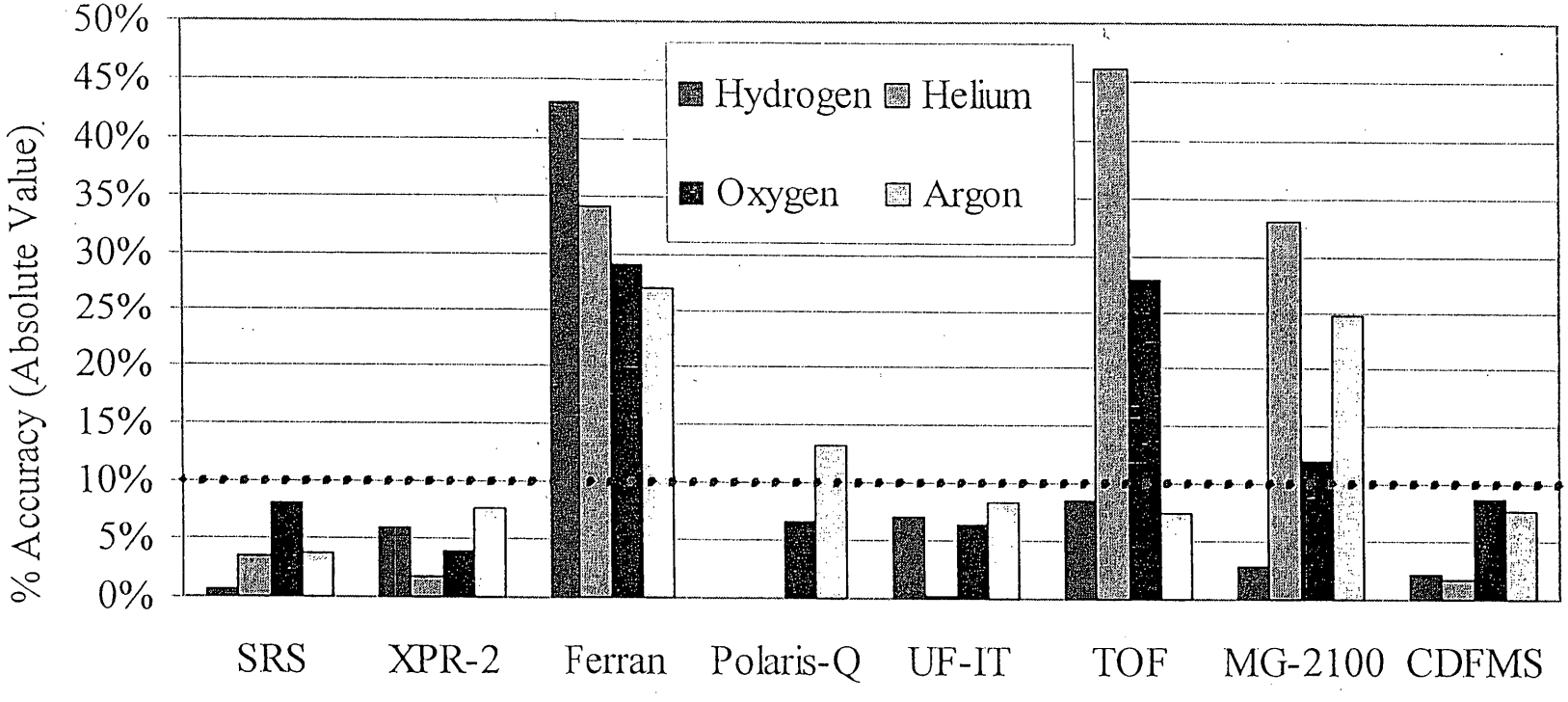
Parameters	Definition	Shuttle Requirements
Accuracy	$\frac{[Test]_{meas} - [Test]_{true}}{[Test]_{true}} \times 100\%$	< 10% or 5ppm, whichever is greater
Precision	$\frac{\sigma_{Test,meas}}{[Test]_{tmeas}} \times 100\%$	< 5% or 3ppm, whichever is greater
Limit of Detection	$3\ \sigma_{zero}$ [a]	H_2, O_2: 25 ppm; He: 100 ppm; Ar: 10 ppm[b]
Response Time	Time required for response from valve change to 95% new reading	10 s
Recovery Time	Time after valve change to reach 5% of previous sample reading (new sample is zero)	30 s
Scan Time	Experiment Time / Scans	1 s
Maximum Size	Sum of Individual Components	3.5×10^4 cm^3
Maximum Weight	Sum of Individual Components	10 kg

[a] Theoretical limit of detection
[b] Measured limit of detection

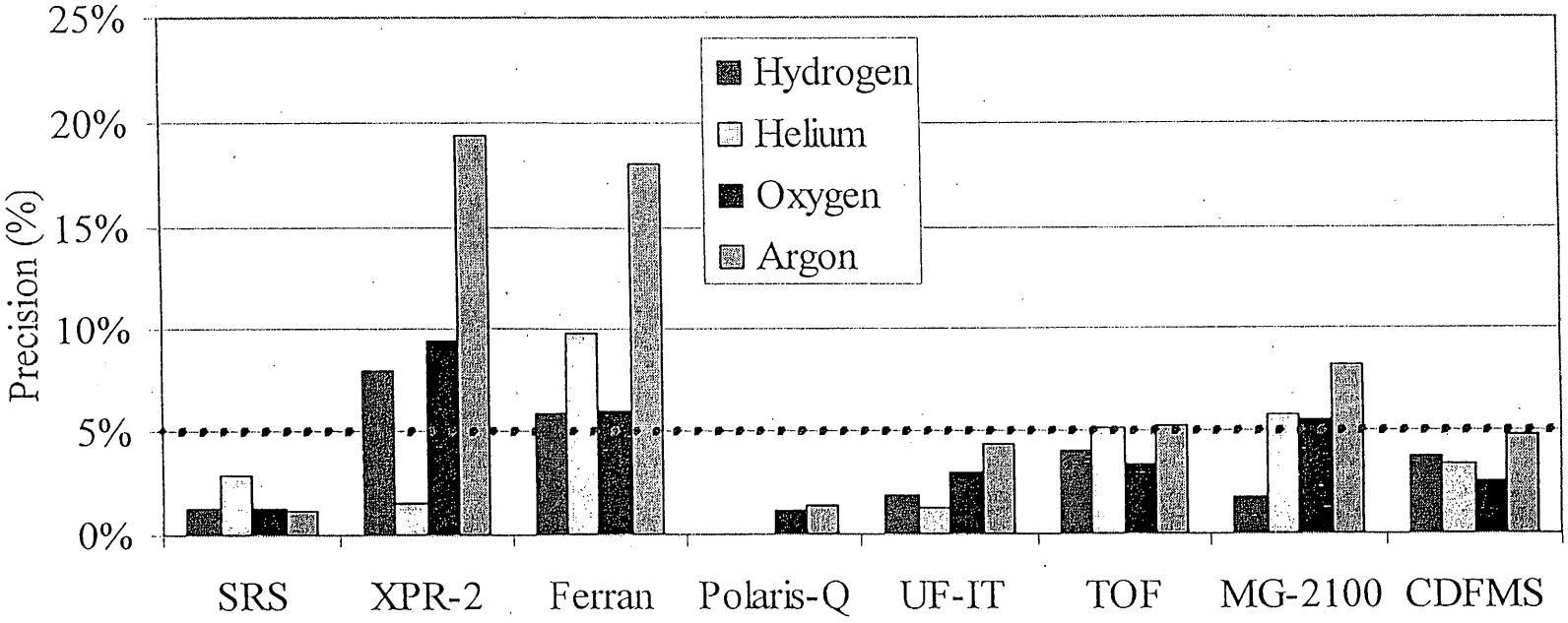
Experimental Scan



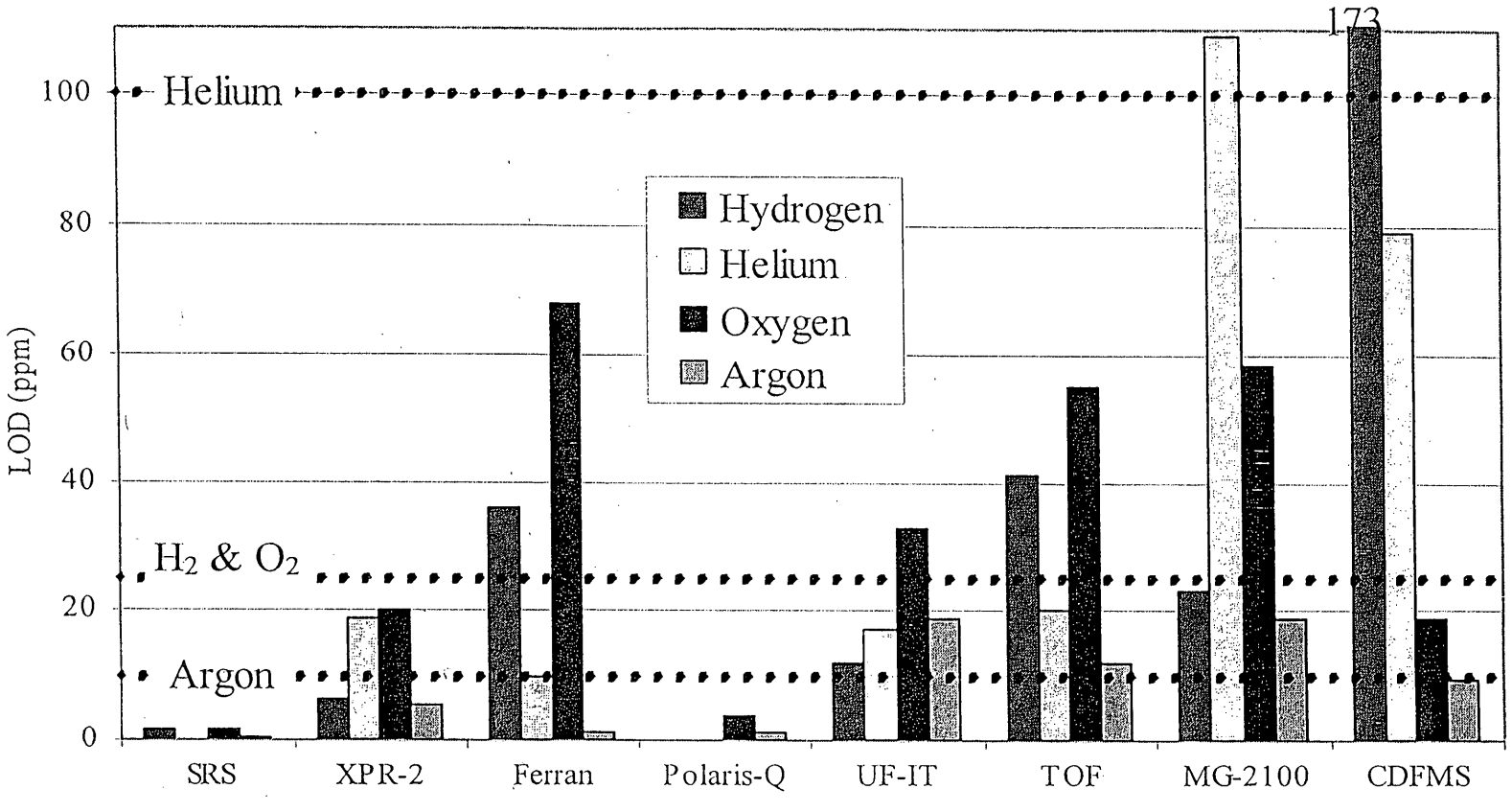
Accuracy


50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
% Accuracy (Absolute Value)
Hydrogen
Helium
Oxygen
Argon
SRS
XPR-2
Ferran
Polaris-Q
UF-IT
TOF
MG-2100
CDFMS

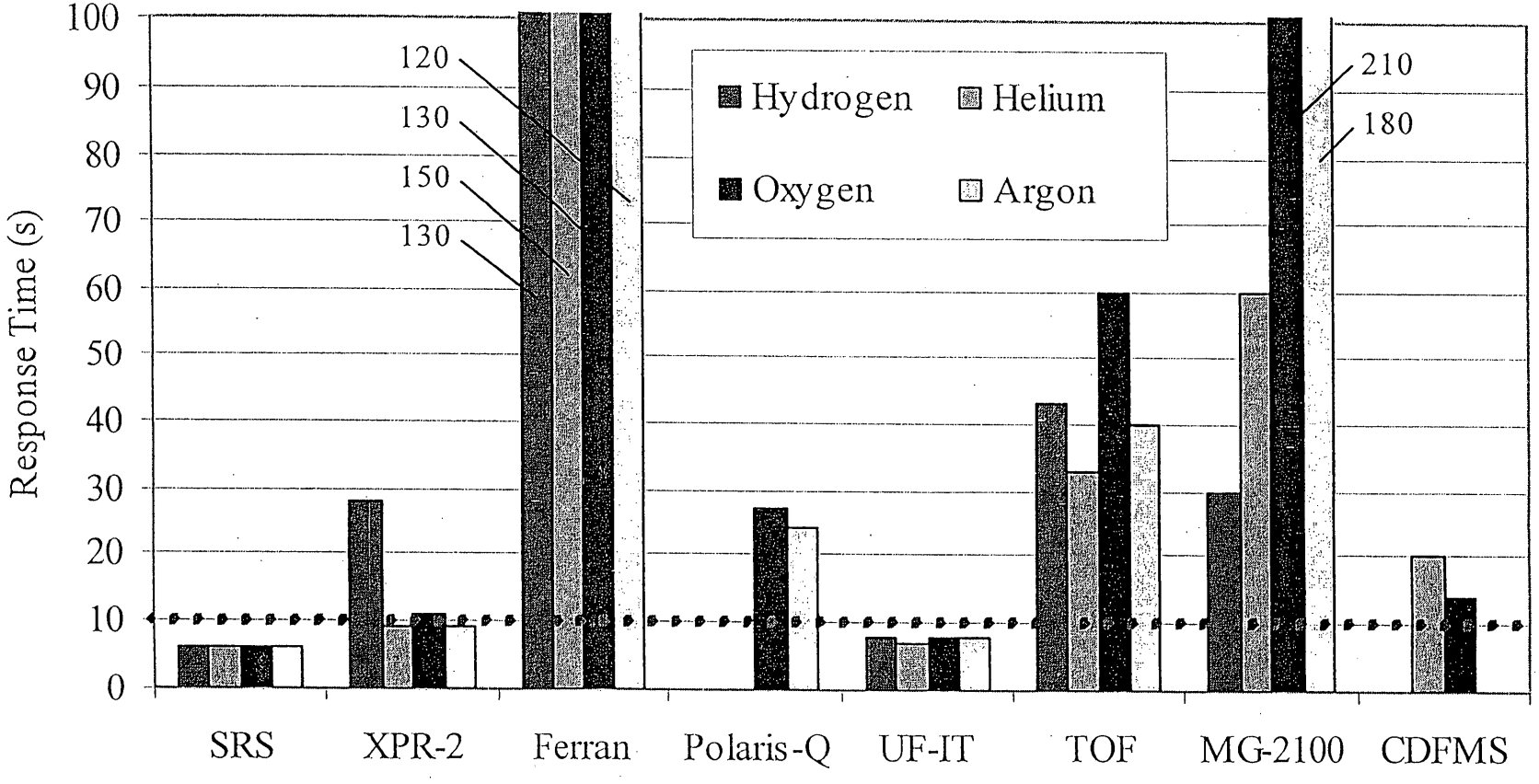
Precision


25%
20%
15%
10%
5%
0%
Precision (%)
Hydrogen
Helium
Oxygen
Argon
SRS
XPR-2
Ferran
Polaris-Q
UF-IT
TOF
MG-2100
CDFMS

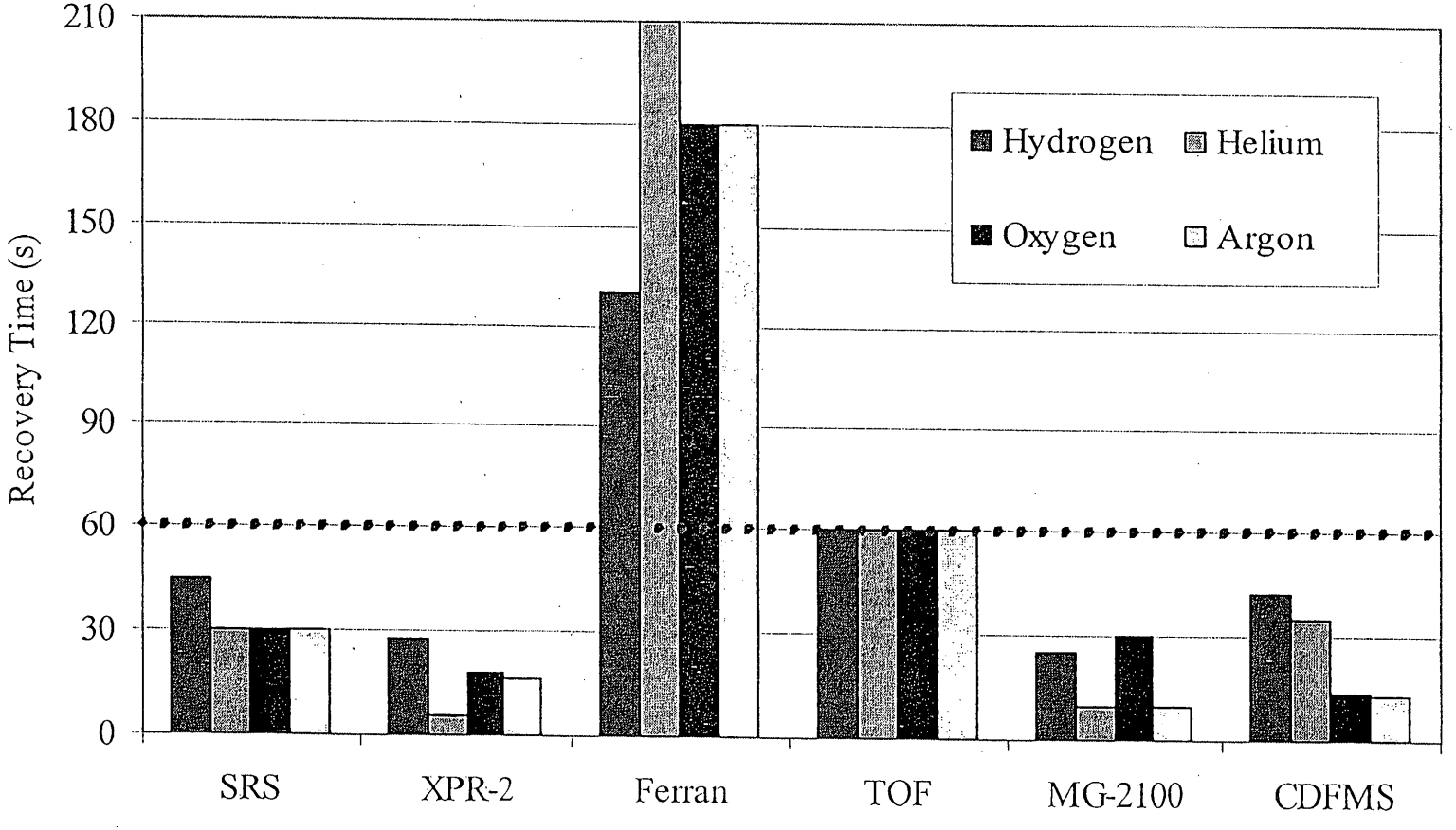
Limits of Detection (LOD)



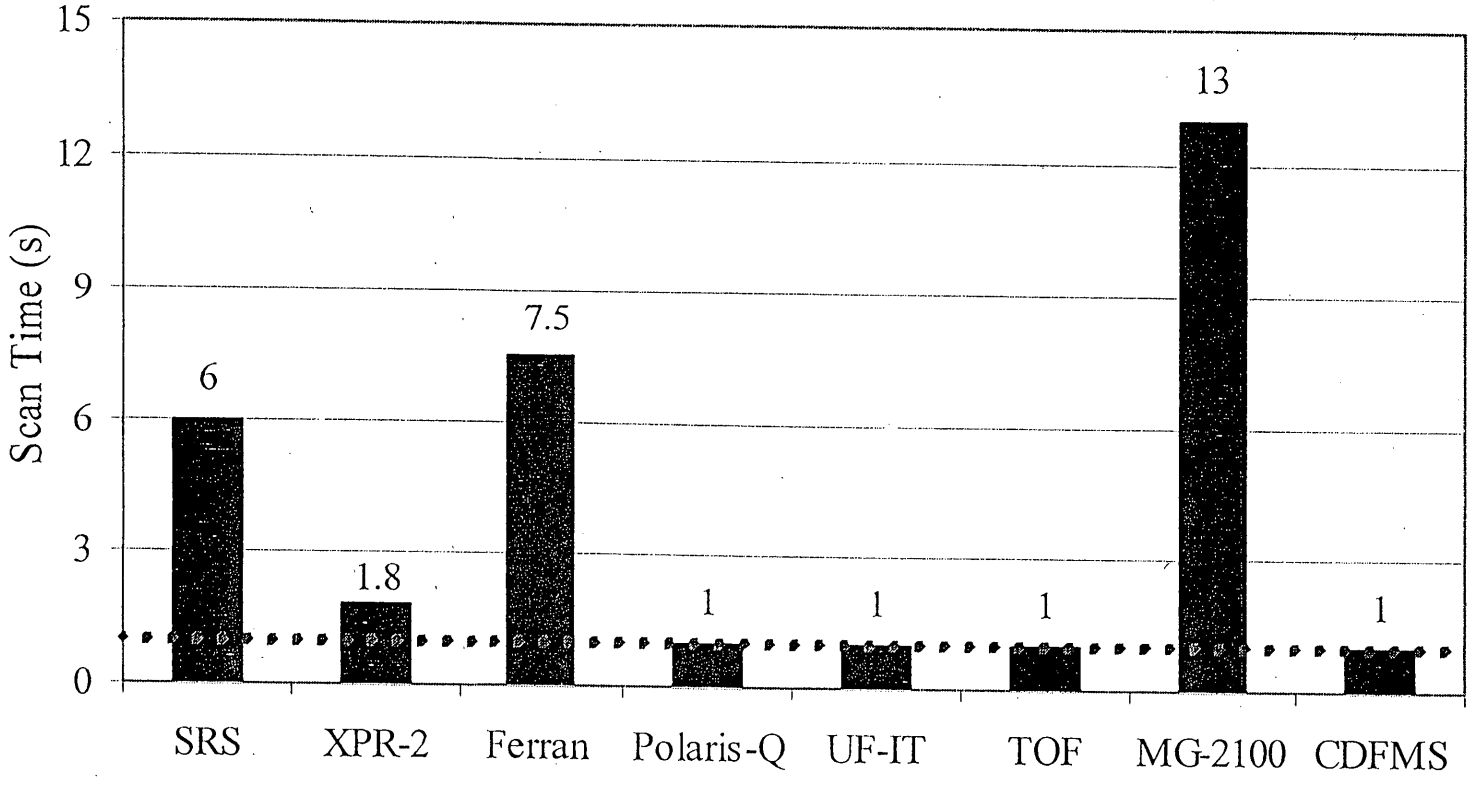
Response Time



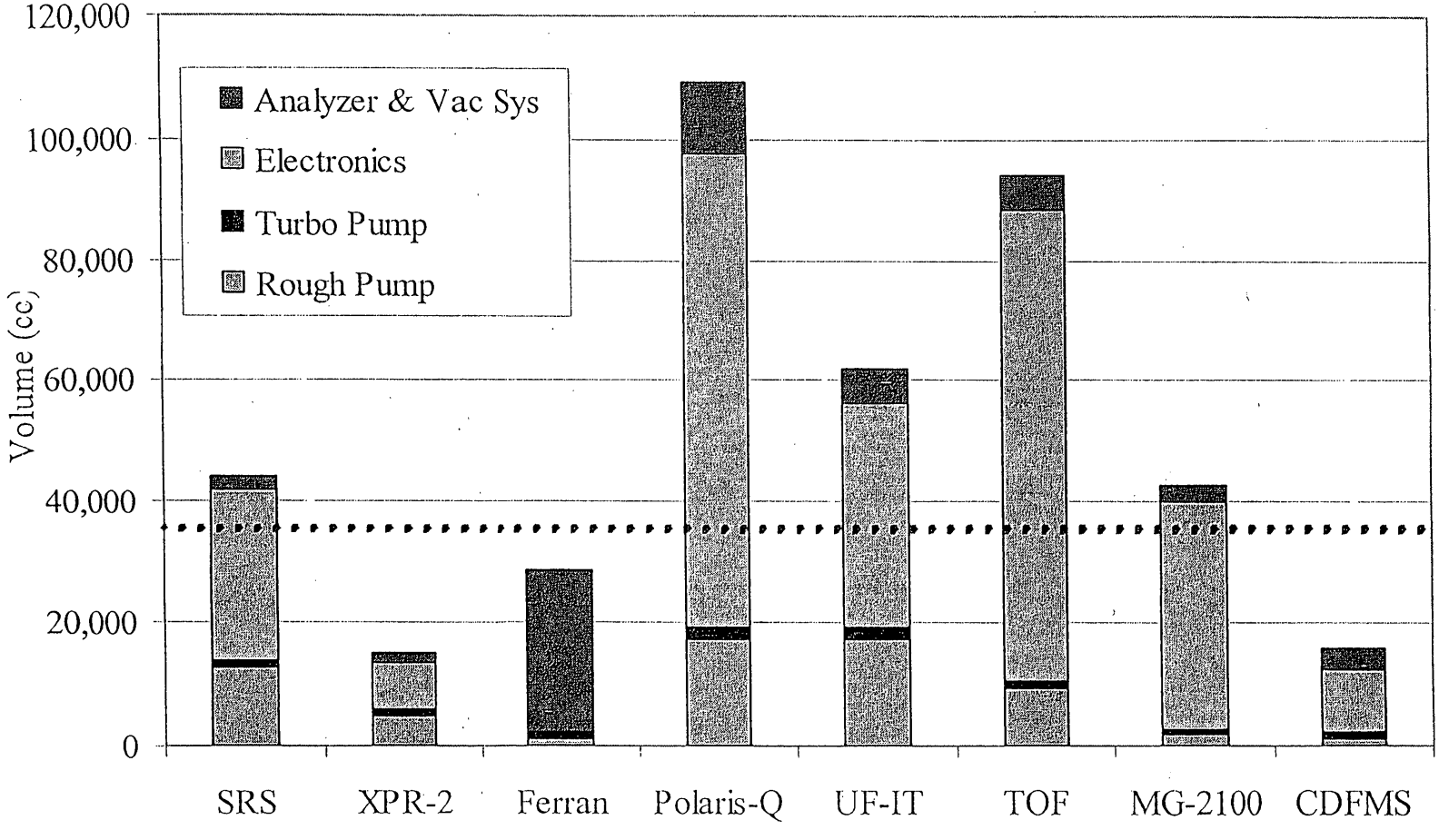
Recovery Time



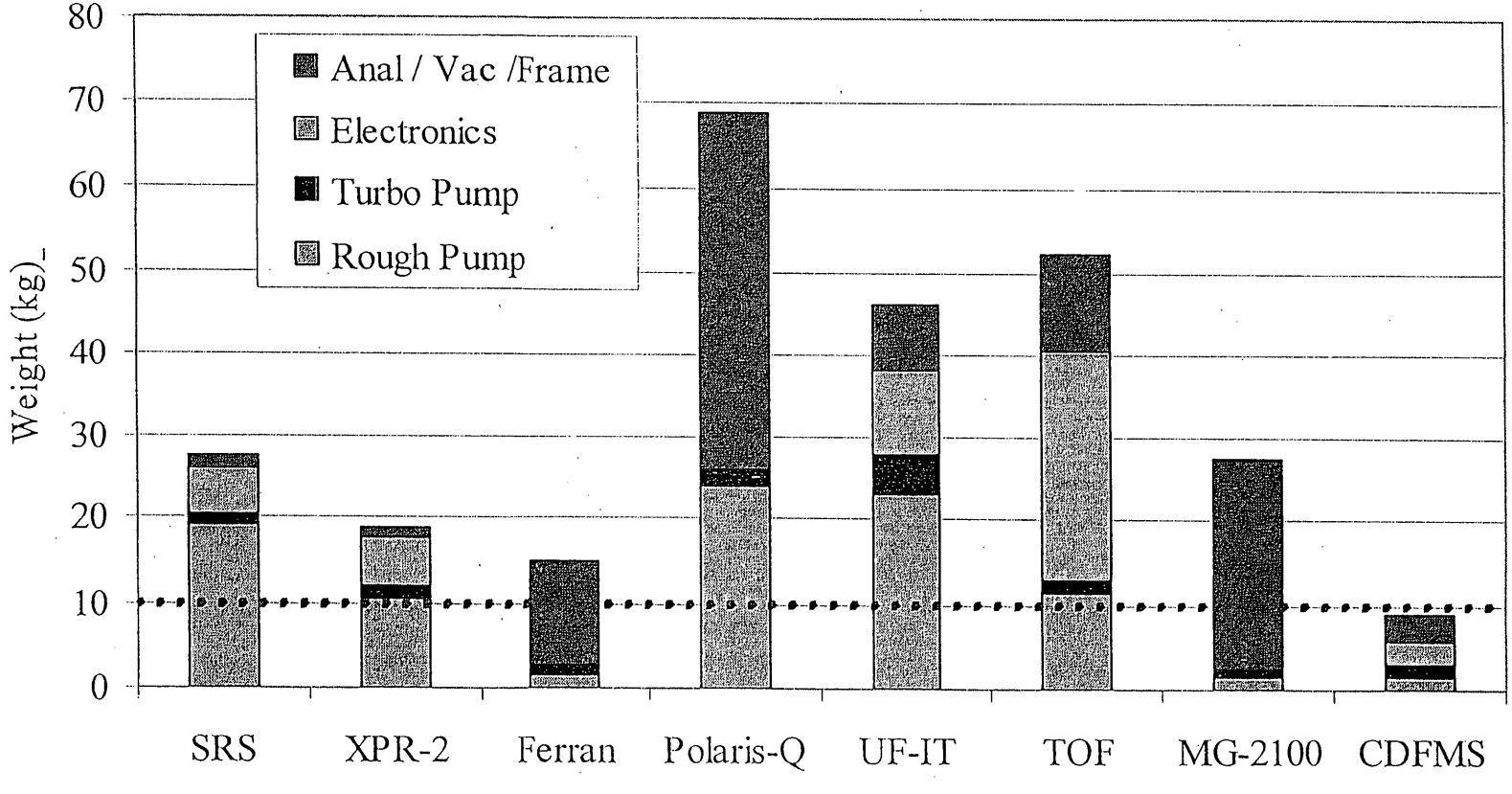
Scan Time


Scan Time (s)
15
12
9
6
3
0
6
1.8
7.5
1
1
1
13
1
SRS
XPR-2
Ferran
Polaris-Q
UF-IT
TOF
MG-2100
CDFMS

System Volume



System Weight



Evaluation Chart

	Accuracy	Precision	LOD	Response	Recovery	Scan Rate	System Volume	System Weight	Score
SRS	2	2	1	2	6	8	6	7	**4.3**
XPR-2	3	8	2	7	5	5	2	6	**4.8**
Ferran	10	10	7	10	10	9	3	6	**8.1**
Polaris-Q	7	3	2	8	8	2	10	10	**6.3**
UF-IT	3	3	6	3	3	2	7	8	**4.4**
TOF	9	6	7	9	7	2	9	8	**7.1**
MG-2100	9	7	10	10	5	10	6	7	**8.0**
CDFMS	4	5	9	8	6	2	2	4	**5.0**
Average[1]	**4.7**	**4.5**	**4.5**	**6.2**	**5.8**	**3.5**	**6.0**	**5.5**	

[1]Excluding Ferran & MG-2100

Conclusions

- Various Mass Analyzer Systems Evaluated

- Several Systems Show Promise
  - Stanford Research Systems RGA-100
  - Inficon XPR-2
  - University of Florida – Ion Trap
  - Compact Double Focus Mass Spectrometer

- Areas that Need Improvement
  - Response Time
  - Recovery Time
  - System Volume
  - System Weight

- Future Work
  - Investigate Techniques to Improve Systems
  - Evaluate Engineering Challenges